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A Cross Layered Approach for Network Selection in Heterogeneous Wireless Networks

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Abstract

Service delivery in a heterogeneous wireless network environment requires the selection of an optimal access network. Selection of a least favorable network can result in insufferable effects such as higher costs or poor service experience. Subsequently, network selection techniques play a vital role in ensuring Quality of Service (QoS) in heterogeneous networks. Network selection in such an environment is determined by several factors with different relative importance. The access network selection problem is usually looked at from the aspect of multi-criteria analysis. The proposed mechanism is based on a modified Multi Criteria Decision Making (MCDM) Scheme that assists the Mobile Subscriber Stations (MSSs) to dynamically select the top candidate network based on the QoS values. The performance analysis reveals that the proposed network selection scheme selects a better network and yields better results**.**

Keywords: *Multi Criteria Decision Making (MCDM) Scheme, Analytic Hierarchy Process (AHP), Grey Relational Analysis (GRA), WiMAX, WiFi, QoS.*

1. Introduction

The Fourth Generation (4G) wireless networks aims at integrating various heterogeneous wireless access networks such as General Packet Radio Service (GPRS), 3G, Wireless Fidelity (WiFi), and Worldwide interoperability for Microwave Access (WiMAX) over an Internet Protocol (IP) backbone. With the integration of different access networks, wider ranges and higher QoS can be provided to the users. The next generation wireless networks are designed to support multimedia services with different traffic characteristics and QoS guarantees and to satisfy different types of Service Level Agreements (SLAs) for increasing the number of mobile users. The integration of different wireless network technologies is required to provide "seamless" interoperability, integration and convergence among the heterogeneous technologies. Several heterogeneous wireless networks like WiMAX and WiFi networks have started functioning together to provide seamless connections to the users.

1.1 IEEE 802.16 - WiMAX

WiMAX, a broadband wireless technology developed by the WiMAX Forum [1] is based on the IEEE 802.16 standard. The main objective is to provide high speed data transfers over the air. It is a technology for next generation with potential applications such as cellular backhaul, hotspot, Voice over IP (VoIP), mobile and broadband connection. It is a standard based wireless technology that provides internet access and multimedia services at very high speed to the end user.

It has a frequency range of about 2 - 11 GHz for Non-Line of Sight (NLOS) and 10 - 66 GHz for Line of Sight (LOS). The signal range for LOS and NLOS are 30 miles and 5 miles respectively.

There are two WiMAX standards - IEEE 802.16d - 2004 (also known as Fixed WiMAX) and IEEE 802.16e - 2005 (also known as Mobile WiMAX). Fixed WiMAX supports fixed and nomadic applications while mobile WiMAX supports mobile, portable, fixed and nomadic applications. WiMAX supports different types of traffics like Best Effort (BE), Unsolicited Grant Service (UGS), nrtPS (nonreal-time Polling Service), rtPS (real-time Polling Service) and ertPS (extended real-time Polling Service).

1.2 IEEE 802.11 - WiFi

WLAN (or WiFi) is an open-standard technology that enables wireless connectivity between equipments and Local Area Networks (LANs). Public access WLAN services are designed to deliver LAN services over short distances. Coverage extends over a 50 to 150 meter radius of the Access Point (AP).

Connection speeds range from 1.6 Mbps to 11 Mbps which is comparable to fixed Digital Subscriber Line (DSL) transmission speed [2].

New standards promise to increase speeds upto 54 Mbps. Today's WLANs run in the unlicensed 2.4 GHz and 5 GHz radio spectrums [3]. The 2.4 GHz frequency is already jam-packed - it is used for several purposes besides WLAN service. The 5 GHz spectrum is a much larger bandwidth providing higher speeds, greater reliability, and better throughput [4].

1.3 Handover

Handover is predominantly used to forward the mobile user's service from a Base Station (BS) in the serving network to another BS in a new network with the same different technology, so as to minimize the processing delay in the overlying area.
Handover is of two types based on the technology of the networks involved namely, Horizontal Handover and Vertical Handover.

Fig. 1 illustrates the WiMAX - WiFi network architecture where the MSS can be handed over to the optimal nearby BS or AP. The handovers based on access networks are:

- **Horizontal Handover:** It takes place between points of attachment supporting the same network technology, for example, between two neighboring BSs of similar cellular network.

- **Vertical Handover:** On the other hand, a vertical handover occurs between points of attachment supporting different network technologies, for example, between an IEEE 802.11 AP and a cellular network BS. Users can move between different access networks. They will benefit from different network characteristics (coverage, bandwidth, frequency of operation, data rate, latency, power consumption, cost, etc.) that cannot be compared directly [5].

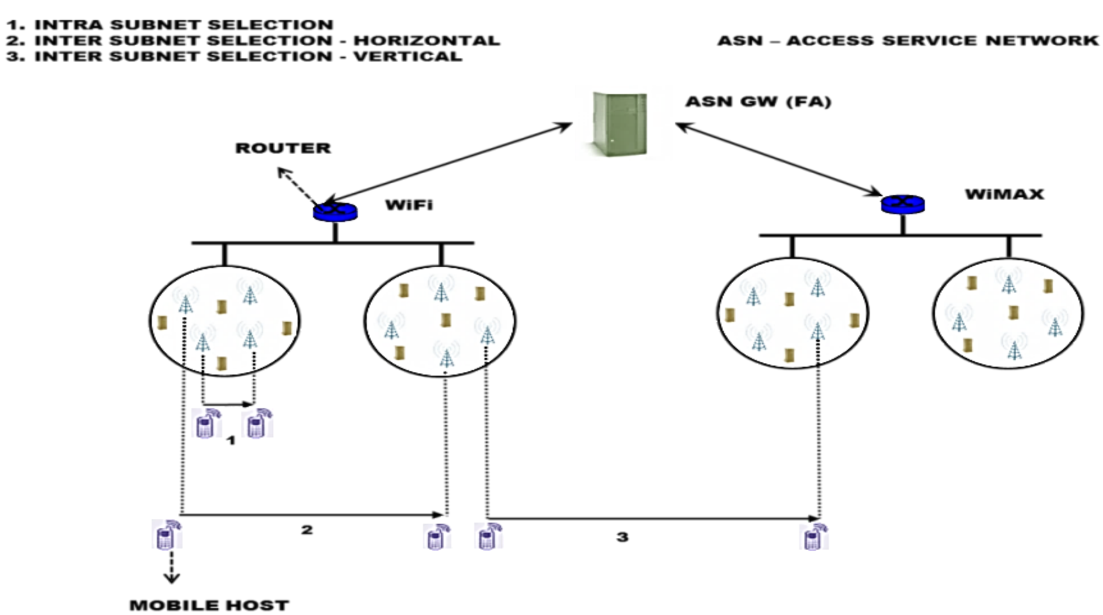

Fig.1 WiMAX - WiFi Network Architecture

1.4 Stages of Handover

A handover process can be split into three stages: Handover Decision, Radio-Link Transfer and Channel Assignment.

- **Handover Decision** involves making a decision to choose the point of attachment to execute a handover and the time/duration of connection.
- **Radio-Link Transfer** is the task of establishing links with the new BS.
- **Channel Assignment** deals with allocation of resources.

2. Multi Criteria Decision Making (MCDM) Schemes

Handover decision problem deals with the network selection from candidate networks of various service providers involving technologies with different criteria. Network selection schemes can be categorized into two types - Fuzzy Logic based schemes and Multiple Criteria Decision Making (MCDM) based schemes.

Three different approaches for optimal access network selection are [6, 7]:

- **Network Centric -** In network centric approach, the decision for access network selection is made at the network side with the goal of optimizing network operator’s benefit. Majority of network centric approaches use game theory for network selection.
- **User Centric -** In the user centric approach, the decision is taken at the user terminal based only on the minimization of the user’s cost without considering the network load or other users. The selection of the access network is determined by using utility, cost or profit functions or by applying MCDM methods. The selection of an access network depends on several parameters with different relative importance such as network and application characteristics, user preferences, service and cost.
- **Collaborative Approaches -** In the collaborative approach, the decision for access network selection is made by considering the profits of both users and network operator. It mainly deals with the problem of selecting a network from a set of alternatives which are categorized in terms of their attributes.

The two processes in MCDM techniques are weighting and ranking. Most popular classical algorithms are Simple Additive Weighting (SAW), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Analytical Hierarchy Process (AHP) and Grey Relational Analysis (GRA).

- In Simple Additive Weighting (SAW), the overall score of a candidate network is determined by the weighting sum of all the attribute values.
- In Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), the chosen candidate network is one which is closest to ideal solution and farthest from the worst case solution.
- Analytical Hierarchy Process (AHP) decomposes the network selection problem into several sub-problems and assigns a weight for each sub-problem.
- Grey Relational Analysis (GRA) is used to rank the candidate networks and select the one with the highest ranking.

3. Related Work

A novel optimization utility is presented in [8] to assimilate the QoS dynamics of the available networks along with heterogeneous attributes of each user. The joint network and user selection is modelled by an evolutionary game theoretical approach and replicator dynamics is figured out to pursue an optimal stable solution by combining both self-control of users’ preferences and self-adjustment of networks’ parameters.

In [9], the authors present a multi-criteria vertical handoff decision algorithm for heterogeneous wireless networks based on fuzzy extension of TOPSIS. It is used to prioritize all the available networks within the coverage of the mobile user and achieves seamless mobility while maximizing end-users' satisfaction.

A network selection mechanism based on two Multi Attribute Decision Making (MADM) methods namely Multiple - Analytic Hierarchy Process (M-AHP) and GRA method is proposed in [10]. The M-AHP is used to weigh each criterion and GRA is used to rank the alternatives.

A survey on fundamental aspects of network selection process is discussed in [11]. It deals with network selection to the always best connected and served paradigm in heterogeneous wireless environment as a perspective approach.

A cross layer architectural framework for network and channel selection in a Heterogeneous Cognitive Wireless Network (HCWN) is proposed in [12]. A novel probabilistic model for channel classification based on its adjacent channels' occupancy within the spectrum of an operating network is also introduced. Further, a modified Hungarian algorithm is implemented for channel and network selection among secondary users.

In [13], a two-step vertical handoff decision algorithm based on dynamic weight compensation is proposed. It adopts a filtering mechanism to reduce the system cost. It improves the conventional algorithm by dynamic weight compensation and consistency adjustment.

A speed-adaptive system discovery scheme suggested in [14] for execution before vertical handoff decision improves the update rate of the candidate network set. A vertical handoff decision algorithm based on fuzzy logic with a pre-handoff decision method which reduces unnecessary handoffs, balancing the whole network resources and decreasing the probability of call blocking and dropping is also added.

A context-aware service adaptation mechanism is presented for ubiquitous network which relies on user-to-object, space-time interaction patterns which helps to perform service adaptation [15]. Similar Users based Service Adaptation algorithm (SUSA) is proposed which combines both entropy theory and Fuzzy AHP algorithm (FAHP).

An approach that adopts a utility function is presented in [16]. It takes into account the users' importance for the considered attributes and the quality offered to these attributes by the available networks. The dynamics of network selection in cooperative wireless networks is exhibited using an evolutionary game theory.

A bandwidth allocation algorithm is proposed in [17] for Constant Bit Rate (CBR) and Variable Bit Rate (VBR) services depending on utility fairness among different networks and the fairness between new arrival and ongoing services. A utility function is introduced whose parameters are determined by the modified multi-state AHP which adapts to different load levels according to dynamic thresholds.

Load balancing algorithm based on AHP proposed in [18] helps the heterogeneous WLAN/UMTS network to provide better service to high priority users without decreasing system revenue.

In [19], a selection policy for heterogeneous wireless networks which applies the AHP algorithm by taking into account the mobility of the user terminals is presented.

An intelligent context-aware solution based on advanced decision approaches like fuzzy logic and AHP that considers both user and service requirements is proposed in [20].

4. Dynamic Analytic Hierarchy Process (DAHP)

AHP was introduced by Saaty [21] with a goal of making decisions about complex problems by dividing them into a hierarchy of decision factors which are simple and easy to analyze.

- The AHP generates a weight for each evaluation criterion according to the decision maker's pairwise comparisons of the criteria. The higher the weight, the more important the corresponding criterion.
- Next, for a fixed criterion, it assigns a score to each option according to the decision maker's pairwise comparisons of the options based on that criterion. The higher the score, the better the performance of the option with respect to the considered criterion.
- Finally, the AHP combines the criteria weights and the options scores, thus determining a global score for each option and a consequent ranking. The global score for a given option is the weighted sum of the scores obtained with respect to all the criteria.

Similarly, in Dynamic AHP (DAHP), the weight of each criterion is assigned dynamically based on the Received Signal Strength Indicator (RSSI) and Signal to Noise Interference Ratio (SINR) values of a MSS with respect to a BS or AP. A network with high RSSI and low SINR is given higher priority. Likewise, the values of both RSSI and SINR are calculated at regular intervals and the weights are assigned. Table 1 shows the possible weights that are assigned to a network based on the parameter values.

DAHP involves the following steps:

- **Step 1:** ***Determination of the objective and the decision factors:*** The decision hierarchy begins with the goal of the decision and proceeds with the objectives from a broad perspective through intermediate levels to the lowest level (Fig. 2).
- **Step 2:** ***Determination of the relative importance of the decision factors with respect to the objective:*** In each level, decision factors are pairwise compared according to their levels of influence with respect to the scale in Table 1. If there are 'n' decision factors, then the total

number of comparisons will be 'n (n - 1)/2'. For qualitative data such as preference, ranking and subjective opinions, it is suggested to use a scale from 1 to 7 as shown in Table 2.

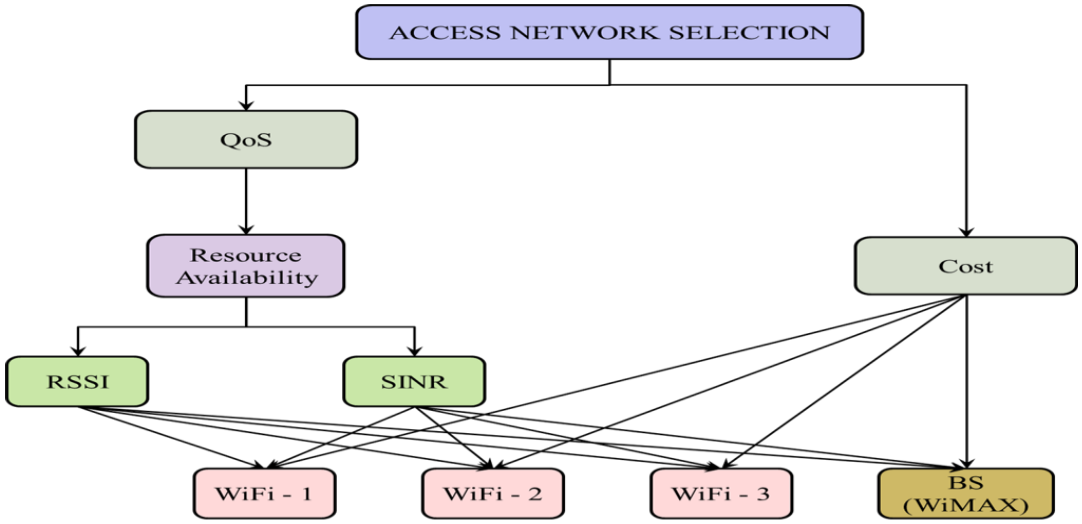

Fig.2 Decomposition of problem in to hierarchy of criteria and alternatives

Table 1: Weights Assignment based on values

RESOURCE AVAILABILITY	RSSI	SINR	SELECT/REJECT
AVAILABLE	High	High	Select (Worst Case)
	High	Medium	Select
	High	Low	Select
	Medium	High	Reject
	Medium	Medium	Select
	Medium	Low	Select
	Low	High	Reject
	Low	Medium	Reject
	Low	Low	Select (Worst Case)

Table 2: Scale of Importance

PREFERENCE LEVELS	VALUES
Equally preferred	1
Equally to moderately preferred	2
Moderately preferred	3
Moderately to strongly preferred	4
Strongly preferred	5
Strongly to very strongly preferred	6
Very strongly preferred	7

Initially, a pair-wise comparison 'n × n' matrix 'A[j][k]' is formed, where 'n' is the number of evaluation criterion considered. Each entry 'a_{jk}' of the matrix represents the importance of the criterion relative to the 'k^{th}' criterion.

- ✓ If $a_{jk} > 1$, then the 'j^{th}' criterion is more important than the 'k^{th}' criterion.
- ✓ If $a_{jk} < 1$, then the 'j^{th}' criterion is less important than the 'k^{th}' criterion.
- ✓ $a_{jk} = 1$, if both the criteria are of equal importance.

Each entry is multiplied with the respective parameter values which increases the accuracy of the criterion weights. The entries 'a_{jk}' and 'a_{kj}' satisfies the following constraint:

$$a_{jk} * a_{kj} = 1 \qquad (1)$$

Also, $a_{jj} = 1$ for all 'j'.

- **Step 3:** ***Normalization and calculation of the relative weights:*** Relative weight is a ratio scale that can be divided among decision factors. The relative weights are calculated by following the steps given below.

  ✓ Each column of matrix A is summed.

  ✓ Each element of the matrix is divided by the sum of its column. The relative weights are normalized. After normalizing, the sum of each column is one.

  ✓ Normalized principle Eigen vector is obtained by finding the average of rows after normalizing.

  ✓ A priority vector is obtained which shows the relative weights among decision factors that are compared. Normalized principle Eigen vector gives the relative ranking of the criteria used.

  ✓ For consistency, largest Eigen value (λ_{max}) is obtained from the summation product of each element of the Eigen vector and sum of columns of matrix A.

$$A = \begin{bmatrix} 1 & 0.5 & 3 \\ 2 & 1 & 4 \\ 0.33 & 0.25 & 1 \end{bmatrix} \xrightarrow[\text{Column Sums}]{\text{Normalized}} \begin{bmatrix} 0.30 & 0.29 & 0.38 \\ 0.60 & 0.57 & 0.50 \\ 0.10 & 0.14 & 0.13 \end{bmatrix} \xrightarrow{\text{Row Averages}} \mathrm{X} = \begin{bmatrix} 0.30 \\ 0.60 \\ 0.10 \end{bmatrix} \quad (2)$$

When many pairwise comparisons are performed, some inconsistencies typically arise. AHP incorporates an effective technique for checking the consistency of the evaluations made by the decision maker when building each pairwise comparison matrix involved in the process and it mainly depends on the computation of a suitable Consistency Index (CI).

The CI is obtained by computing the scalar 'x' as the average of the elements of the vector whose 'jth' element is the ratio of the 'jth' element of the vector 'A*w' to the corresponding element of the vector 'w'.

$$\mathrm{CI} = \frac{\lambda_{max} - n}{n-1} \quad (3)$$

A perfectly consistent decision maker should always yield CI=0. Small values of inconsistency may be tolerated. RI is the Random Index, i.e. the CI when the entries of 'A' are completely random. The values of RI for small problems ($m \leq 10$) are shown in Table 3.

In particular, if $\frac{CI}{RI} < 0.1$, then inconsistencies are tolerable and a reliable result may be expected from AHP. Otherwise the pairwise comparison should be initiated from the beginning.

Table 3: Values for Random Index

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

5. Performance Analysis

A heterogeneous network scenario is simulated using ns2. The simulation parameters are shown in Table 4.

The proposed DAHP scheme offers better performance when compared to AHP in terms of delay, throughput and Packet Loss Ratio (PLR).

Table 4: Simulation Parameters

PARAMETER	VALUE
MAC	Mac/802.16 & 802.11
Packet Size	5000
Bandwidth	1 Mbps
Queue Length	50
Routing	DSDV
Simulation time	50 Sec

As shown in Fig. 3, the delay involved in the proposed DAHP scheme is less. The average delay of AHP scheme is 1.6 times more than that of DAHP.

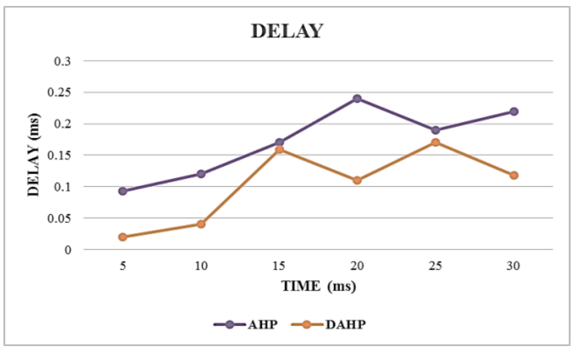

Fig.3 Delay

The Throughput of DAHP is better when compared to the existing AHP scheme (Fig. 4). The proposed DAHP scheme offers 1.3 times more throughput when compared to conventional AHP.

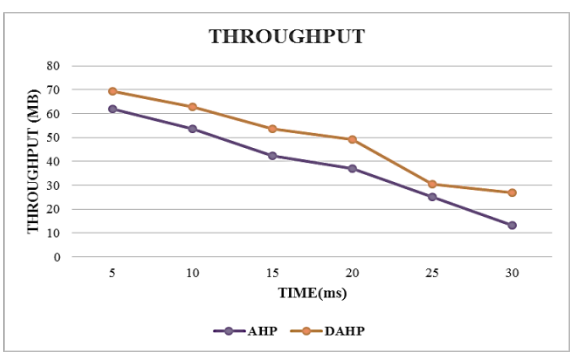

Fig.4 Throughput

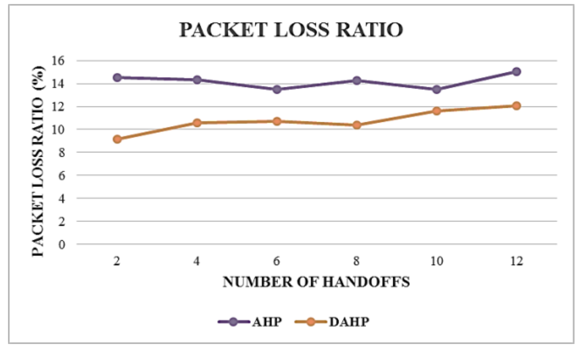

Fig.5 Packet Loss Ratio

Similarly, as shown in Fig. 5, the Packet Loss Ratio (PLR) of DAHP is less when compared to the former scheme as network selection is done dynamically based on the QoS values. The PLR of DAHP is 1.3 times lower when compared to the existing scheme.

6. Conclusion

A novel network selection algorithm for optimal wireless network selection in heterogeneous environment is developed, where the PHYsical layer parameters such as Signal Strength & Noise Ratio are integrated. The proposed network selection algorithm provides seamless connection for the users over the heterogeneous network and enables the MSSs to forward the calls to the optimal network without dropping it. The simulation results reveal that the proposed network selection scheme can efficiently decide the trade-off among user preference, service application and network condition. In addition, the priorities of options can be decided based on approximate comparisons of the QoS parameters instead of exact values of the QoS parameters in the heterogeneous system with only two network alternatives, which means simpler implementation. In the future, the proposed scheme can be used in more comprehensive situations with more network alternatives and selection criteria.

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